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AFOEHL REPORT
89-038EH0087EAC

Evaluation of Rocket Motor Exhaust and Liner Combustion By-products

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May 1989

Final Report

AF Occupational and Environmental Health Laboratory
Human Systems Division (AFSC)
Brooks Air Force Base, Texas 78235-5501

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This report has been reviewed and is approved for publication.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS NA
2a. SECURITY CLASSIFICATION AUTHORITY NA	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE NA	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) 89-038EH0087EAC	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION AF Occupational and Environmental Health Laboratory 6b. OFFICE SYMBOL (If applicable) ECH	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Brooks AFB TX 78235-5501	7b ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Same as 6a 8b. OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification)
Evaluation of Rocket Motor Exhaust and Liner Combustion By-products (U)

12. PERSONAL AUTHOR(S)
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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Final	FROM 3-6 Aug TO 88	May 1989	30

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Rocket Motor Exhaust; Liner Combustion; By-Products; Atkins; High Speed Sled

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The AF Occupational and Environmental Health Laboratory conducted an evaluation of rocket motor exhaust and liner combustion by-products after four high speed rocket motor sled tests at the Holloman AFB Test Track. The Zuni, HVAR (High Velocity Air Rocket), and Nike rocket motors were evaluated. Results indicated airborne concentrations of nitric oxide, nitrogen dioxide, carbon monoxide, camphor and diethyl phthalate would pose the greatest health risk to test track workers. Recommendations were made to have track crews wear personal protective equipment to control or reduce exposures.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Isaac Atkins, Jr., Captain, USAF, BSC	22b TELEPHONE (Include Area Code) (512) 536-9001 22c OFFICE SYMBOL AFOEHL/ECH

DD Form 1473, JUN 86 — Previous editions are obsolete — SECURITY CLASSIFICATION OF THIS PAGE

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I. INTRODUCTION

A. Background

The 6585th Test Group uses an assortment of expendable rocket motors to conduct a variety of high speed sled tests at Holloman AFB NM. Actual flight conditions are simulated using rocket motors to accelerate a sled train down a ten mile test track (Figure 1). Test components such as ejection seats are attached to the sled along with photo-optical surveillance equipment. Sled tests are used to evaluate test components for structural integrity and validate load and stress design parameters.

Test track workers (who conduct sled recovery operations within minutes of rocket motor burnout) have experienced symptoms of nausea, vomiting, headache, and eye and skin irritation. Annual physical examinations were used to monitor the workers' health; however, examinations were deleted over five years ago. Environmental and safety personnel have evaluated past health-related complaints and issued reports which concluded "no problem" to "possible health hazards".(1)

Track safety and sled recovery crews conduct sled recovery operations after the test sled is launched down the track. Track safety crews survey the test area for ignitable solid rocket fuel and determine safe response conditions. Then sled recovery crews arrive and secure the sled and, if necessary, retrieve critical test components. Periodically, track safety and sled recovery crews are required to immediately respond and conduct sled recovery operations within minutes of rocket motor burnout. This exposes them to rocket motor exhaust and liner combustion by-products. Rocket motor exhaust chemical ingredients are listed in Table 1. The rocket motor liner insulates the rocket motor's solid rocket fuel from its outer metal casing. Liner materials for frequently used rocket motors are listed in Table 2.

The 833rd Medical Group/SGPB, Holloman AFB conducted limited air sampling using nitrogen oxides and hydrogen chloride (HCl) detector tubes. Results indicated track crews were exposed to high levels of nitrogen oxides (8 times the Short Term Exposure Limit [STEL], 5 parts per million [ppm]) and high levels of HCl which exceeded the limits of the detector tubes. The 833 SGPB recommended test track crews wear self-contained breathing apparatuses and all other personnel not enter the area until dissipation of the exhaust cloud.(2) However, the 6585th Test Group recommended a more detailed evaluation be conducted before placing test track crews in expensive and cumbersome breathing apparatuses that would interfere with their ability to safely conduct sled recovery operations.(3) Therefore, the 833 SGPB requested the AF Occupational and Environmental Health Laboratory (AFOEHL) perform a detailed evaluation of rocket motor exhaust combustion by-products and if necessary recommend personal protective equipment.

During the period 3-6 Aug 88 AFOEHL personnel met with track safety and sled recovery crews, base bioenvironmental engineering and test track management personnel. Suspected hazards and symptoms attributed to rocket motor exhaust and liner combustion by-products exposure were discussed. Two potentially hazardous exposures were identified: (1) exposure of safety crews to rocket motor exhaust combustion by-products during prelaunch tethering operations, and (2) exposure of sled recovery crews to rocket motor exhaust and liner combustion by-products during high speed sled test recovery operations. Surveys were scheduled to investigate both occupational exposures.

During the period 25-31 Aug 88 AFOEHL personnel collected air samples after two high speed rocket motor sled tests. Results indicated track crews were exposed to minimal levels of hydrogen chloride (HCl), nitric oxide (NO), nitrogen dioxide (NO_2), hydrogen sulfide (H_2S), and carbon monoxide (CO) during Zuni and High Velocity Air Rocket (HVAR) sled recovery operations. Rocket motor liner combustion by-products were collected using Tenax^R and charcoal tubes. Camphor and diethyl phthalate were identified as major Zuni and HVAR rocket liner contaminants.

During the period 14-19 Nov 88 AFOEHL personnel collected air samples after two more high speed rocket motor sled tests. Results indicated NO, NO_2, CO and diethyl phthalate would pose the greatest health risk to test track workers during Nike rocket motor sled tests. Recommendations were made to have track crews wear personal protective equipment to control or reduce exposures.

B. Objective of Current Report

The purpose of this report is to explain how AFOEHL personnel determined ambient levels of NO, NO_2, CO, HCl, H_2S, camphor, and diethyl phthalate after four high speed rocket motor sled tests at Holloman AFB Test Track.

C. Survey Personnel

Capt Isaac Atkins Jr., Consultant, Industrial Hygiene Engineer
1Lt Mark Dibben, Deputy Chief of Air Analysis, Analytical Services Division

II. METHOD AND RESULTS

A. Zuni and HVAR Motor Sled Tests

The 6585th Test Group conducted a Zuni rocket motor (Figure 2) sled test on 26 Aug 88 and an HVAR (Figure 3) sled test on 31 Aug 88. The Zuni sled test was conducted to investigate monorail sled braking. A Zuni rocket motor accelerated a small monorail sled with a braking wedge attached to the front to a velocity of 2367 feet per second (fps). Once the sled reached a speed of 2000 fps it impacted 150 feet of suspended split solid foam blocks then coasted to a stop. The HVAR sled test was conducted to gather velocity profile data of the HVAR motor sled and was used to train track crews to perform multiple sled tests within a three hour period. The test was requested by the Air Force Flight Test Center for evaluation of an infrared (IR) system which will be used to intercept launched missiles during an enemy attack. Zuni and HVAR rocket motor exhausts and rocket motor liner combustion by-products were sampled during sled recovery operations. Refer to Table 3 for Sampling Protocol. Sampling llocations are shown in Figures 4 and 5.

Two-20 liter Tedlar[R] bags were filled with Zuni and HVAR rocket motor exhaust and liner combustion by-products using Alpha-1[R] low flow pumps. Both bags were analyzed in the field for NO, NO_2 and CO using a CSI 2200 NO/NO_2 Analyzer and a CO 101 Analyzer, respectively. Ambient concentrations of HCl were measured using an Interscan HCl Analyzer. Data are presented in Tables 4 and 5. Impingers were used to collect ambient concentrations of H_2S. Data are presented in Table 6. Area samples of Zuni and HVAR liner combustion by-products were collected using charcoal and Tenax tubes. Samples were screened for organic contaminants using gas chromatography/mass spectrometry (GC/MS). Data are presented in Table 7. Results indicated diethyl phthalate and camphor were major Zuni and HVAR rocket motor liner airborne contaminants.

B. Nike Rocket Motor Sled Tests

The 6585th Test Group conducted a Nike rocket motor (Figure 6) sled test on 16 and 17 Nov 88. The first test evaluated load and stress parameters of the Multiple Access Seat Ejection Sled (MASE). Seven Nike rocket motors were used to accelerate the MASE sled to a maximum velocity of 476 knots equivalent air speed (KEAS). The second test evaluated structural integrity of an F-16 forebody and determined performance of its forward and aft ejection seats and glareshield. The seats were ejected from the F-16 forebody at 350 and 600 KEAS. Five Nike rocket motors were used to accelerate the F-16 forebody sled train. Nike rocket motor exhaust and rocket motor liner combustion by-products were sampled during sled recovery crew operations. The same sampling protocol was used as described in Table 3. Sampling locations are shown in Figures 7 and 8.

An Alpha-1 low flow pump was used to fill a 20 liter Tedlar bag with Nike rocket motor exhaust and liner combustion by-products. The bag sample was analyzed in the field for NO, NO_2, and CO. Ambient concentrations of HCl ranged from 0.8 ppm (10 minutes after launch) to 0.2 ppm (25 minutes after launch). Data are presented in Tables 8 and 9. Impingers were used to collect ambient concentrations of H_2S. Data are presented in Table 10. Area samples of Nike rocket motor liner combustion by-products were collected using charcoal tubes. Because the Nike rocket motor contained a different liner, two samples were screened for organic chemical contaminates using GC/MS. Data are presented in Table 11. Results indicated diethyl phthalate as the major Nike rocket motor liner airborne contaminant with no detectable levels of camphor (<0.1 mg/m^3). Subsequent samples were analyzed for diethyl phthalate. Data are presented in Table 12.

III. DESCRIPTION AND CALIBRATION OF DIRECT READING INSTRUMENTS

A. CSI 2200 Nitric Oxide and Nitrogen Dioxide Analyzer

The CSI 2200 (Figure 9) utilizes the photometric measurement of chemiluminescent light to determine NO and NO_2 airborne concentrations. The chemiluminescent method is based on the principle that NO reacts with ozone (O_3) to produce NO_2 in an excited state and oxygen. The amount of light produced by this reaction is proportional to the ppm concentration of NO. To measure NO_2, the sampied air was drawn past a chemical converter by a miniature pump. The converter reduced NO_2 to NO so that ambient concentrations of NO_2 could be detected and measured as NO. A solenoid valve was used to alternate the incoming air sample past the converter to detect only NO_x and direct it through the converter to permit measurement of NO + NO_2 which was defined as NO_x. An electronic subtraction circuit measured NO_2 as the difference between NO_x and NO. The instrument detects and measures NO and NO_2 concentrations ranging from 0 to 5 ppm.

The instrument was calibrated using a two liter volumetric gas syringe to make up calibration gases from known concentrations of NO and NO_2. This was done by volumetrically diluting measured amounts of 24.72 ppm NO, in nitrogen and 24.72 ppm NO_2, in nitrogen (Scotty Calibration Gases) with zero air. Five concentrations spanning the range of the instrument were prepared. A calibration curve was prepared with the analyzer response plotted against actual concentrations (Figure 10). The slope, intercept and correlation coefficient were calculated by linear regression. Calibrations were performed before and after every use.

B. Carbon Monoxide 101 Analyzer

The CO 101 analyzer (Figure 11) uses a carbon monoxide sensor to measure ambient concentrations of CO. The sampled air was drawn past an electrochemical diffusion sensor by a miniature pump. The sensor consisted of an anode, cathode and electrolyte. The air was electrochemically oxidized by the air cathode which produced a sensor signal proportional to ambient CO concentrations. The instrument detects and measures CO concentrations ranging from 0 to 4000 ppm.

The instrument was calibrated by filling a two liter bag with a known concentration (50.2 ppm, ECO Span Calibration Gas) of CO and allowing the instrument to evacuate the bag. Calibrations were performed before and after every use.

C. Interscan Hydrogen Chloride Analyzer

The compact and portable Interscan HCl analyzer (Figure 12) used an electrochemical voltametric sensor to measure ambient concentrations of HCl. The sampled air was drawn past the sensor using a self-contained miniature pump. Sample concentrations were displayed directly in ppm. The instrument detects and measures HCl concentrations ranging from 0 to 50 ppm.

The instrument was calibrated using two permeation tubes to generate two known concentrations of HCl (0.6 and 1.2 ppm). The generated concentrations varied directly with the permeation rate and inversely with the flow rate of the carrier gas (air). The calibration gas concentration was calculated using the following equation:

$$\text{Gas Concentration (ppm)} = \frac{P \times K}{F}$$

Where K = 24.45 liters /MW (MW = 36 grams), F is the carrier gas flow rate (1000 cc/min) and P is the permeation rates 0.867 or 1.731 µg/min at 30 degrees Celsius certified by the manufacturer DYNACAL. Calibrations were performed before and after every use.

IV. DISCUSSION AND CONCLUSIONS

The 833rd Medical Group/SGPB requested AFOEHL perform a detailed evaluation of rocket motor exhaust combustion by-products and if necessary recommend personal protective equipment. We met with track safety and sled recovery crews and discussed suspected hazards and symptoms attributed to rocket motor exhaust and rocket motor liner combustion by-products exposure. Air sampling was conducted after four high speed sled tests. Rocket motor exhaust and liner combustion by-products from the Zuni, HVAR, and Nike rocket motors were evaluated. Results indicated airborne concentrations of NO, NO_2, CO, camphor and diethyl phthalate would pose the greatest health risk to test track workers. Although not sampled, historical rocket motor data indicated HCl and H_2S would pose the greatest health risk during prelaunch tethering operations.

During sled recovery operations, track safety and sled recovery crews are exposed to rocket motor exhaust and liner combustion by-products. Exposures usually range from 5 to 10 minutes. Because of short exposure times (less than 15 minutes), sample results were evaluated using the STEL, Ceiling, and Excursion Limits. The STEL is defined as a 15-minute time-weighted average (TWA) exposure which should not be exceeded at any time during the workday. The Ceiling level is defined as the concentration that should not be exceeded during any part of the working exposure. Excursion limits are used when there is not enough toxicological data available to warrant a STEL. Excursion limits are based on the concept that short-term exposures do not exceed three times the TWA for more than a total of 30 minutes during a workday and under no circumstances should they exceed five times the 8-hour TWA.(4)

As shown in Tables 4 and 5, Zuni and HVAR NO, NO_2, and CO concentrations were far below the recommended level of 125 ppm (excursion limit), 5 ppm (STEL) and 400 (STEL), respectively as recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). Zuni rocket motor HCl levels ranged from 3.8 ppm (10 minutes after launch) to 0.2 ppm (25 minutes after launch) while HVAR HCl levels were reported to be less than the limit of detection (<1 ppm). HCl has a ceiling level of 5 ppm. Both rocket motors reported no detectable levels of H_2S (<0.1 mg/m^3). Qualitative analysis of the Zuni and HVAR rocket exhaust identified camphor, and diethyl phthalate as major rocket motor liner airborne contaminants for both motors. Camphor is used as a plasticizer for cellulose nitrate and other explosives and lacquers. Diethyl phthalate is used as a solvent for cellulose acetate in manufacturing varnishes and dopes.(5) As shown in Table 2, the Zuni and HVAR rocket motor liners consisted of ethyl cellulose and cellulose acetate, respectively. We concluded that sled recovery crews were exposed to minimum levels of NO, NO_2, CO, HCl, and H_2S during high speed Zuni and HVAR sled test recovery operations; however, combustion of the Zuni and HVAR rocket motor liners exposed track crews to a variety of organic contaminants including concentrations of heated camphor and diethyl phthalate.

On the other hand, Nike rocket motor sampling results (Tables 8 and 9) indicated sled recovery crews were exposed to high levels of NO and NO_2 (levels exceeded the instruments' scale, greater than 5 ppm). CO levels exceeded the STEL concentration of 400 ppm. HCl levels ranged from 0.8 ppm (10 minutes after launch) to 0.2 ppm (25 minutes after launch). H_2S levels were reported to be less than the detection limit (0.1 mg/m^3). Qualitative analysis of the Nike rocket motor exhaust identified diethyl phthalate as the major Nike rocket motor liner airborne contaminant. Camphor levels were reported to be less than the limit of detection (<0.0003 mg/m^3). As shown in Table 12, three diethyl phthalate samples exceeded the diethyl phthalate excursion limit of 25 mg/m^3. The Nike rocket motor liner is made of an unknown material called Flamermastic. We concluded that sled recovery crews were exposed to high levels of NO, NO_2 and CO during high speed Nike rocket motor sled test recovery operations. In addition, combustion of the Nike rocket motor liner exposed track crews to high concentrations of diethyl phthalate.

Track safety and sled recovery crews reported symptoms of nausea, vomiting, headache, and eye and skin irritation. Inhalation of nitric oxide and nitrogen dioxide can cause nose and upper respiratory tract, throat, and eye irritation. Inhalation of carbon monoxide can cause symptoms of nausea, headache, and tachypnea. Inhalation of camphor can cause skin and eye irritation, nausea, vomiting and diarrhea.(6) Exposure to heated vapor concentrations of diethyl phthalate can cause transient irritation of the nose and throat.(7) We concluded that exposure to NO, NO_2, CO, camphor and diethyl phthalate probably caused the health-related symptoms reported by safety and sled recovery crews.

Although not sampled, historical rocket motor data indicated HCl and H_2S would pose the greatest health risk to test track workers during prelaunch tethering operations.(8,9) Exhaust plume photos indicated a large exhaust plume is produced during prelaunch tethering operations. Depending on environmental conditions, the exhaust plume may persist for several minutes after take-off. Safety crews reported entering the exhaust plume during emergency sled recovery operations. Because of these findings, the following recommendations are provided to reduce track safety and sled recovery crews exposure to rocket motor exhaust and liner combustion by-products.

V. RECOMMENDATIONS

A. Recommend test track workers be informed about potential health hazards associated with exposure to rocket motor exhaust and liner combustion by-products. All workers should understand exposure can occur through inhalation, ingestion, and skin absorption and that short-term (5 to 10 minutes) periodic exposure to NO, NO_2, and HCl concentrations usually result in short-term upper respiratory tract health effects. Short-term periodic exposure to CO, camphor and diethyl phthalate can cause symptoms of nausea, headache, tachypnea and eye, nose, throat, and skin irritation.

B. Recommend track safety crews wear self-contained breathing apparatuses (SCBSs) operated in the positive pressure mode and protective clothing during prelaunch tethering operations which require immediate response. Protective gloves and clothing made of polyvinyl chloride (PVC) are relatively inexpensive and have been shown to provide excellent protection against concentrations of HCl.(10) This is recommended because historical rocket motor data indicated HCl and H_2S are major by-products of the rocket motor exhaust and safety crews reported entering the exhaust plume prior to its dissipation. Chemically treated detector tape or detector tubes are excellent devices to use to estimate safe HCl or H_2S levels during immediate response conditions. Both devices are inexpensive and easy to use.

C. Recommend sled recovery crews wear approved full-face air-purifying organic vapor cartridge respirators equipped with a high efficient particulate filter during sled recovery operations. Sled recovery crews are exposed to a variety of organic chemical contaminates including concentrations of heated camphor and diethyl phthalate. No special protective clothing is recommended. Normal clothing (i.e., long sleeve skirts, long pants and gloves), if worn properly (sleeves rolled down) can provide adequate protection against skin irritation and adsorption.

D. Recommend establishment of a respiratory protection program which, at a minimum, meets the requirements of 29 CFR 1910.134. Respirators selected must be approved by the Mine Safety and Health Administration or by the National Institute of Occupational Safety and Health (NIOSH). Base bioenvironmental engineering should be consulted for proper selection of approved respirators and cartridges.

E. Recommend when possible, sufficient time be allowed for the rocket motors to cool down before conducting sled retrieval operations. Three to four hours should be sufficient.

F. Recommend personnel other than safety and recovery crews (i.e., photographers, box house crew, observers) remain at a minimum of ten feet upwind to avoid inhalation of rocket motor exhaust and liner combustion by-products.

G. Minimal surveillance of test track workers should comply with AFOSH Standard 161-1, Respiratory Protection.

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Figure 1

HOLLOMAN AFB TEST TRACK NM

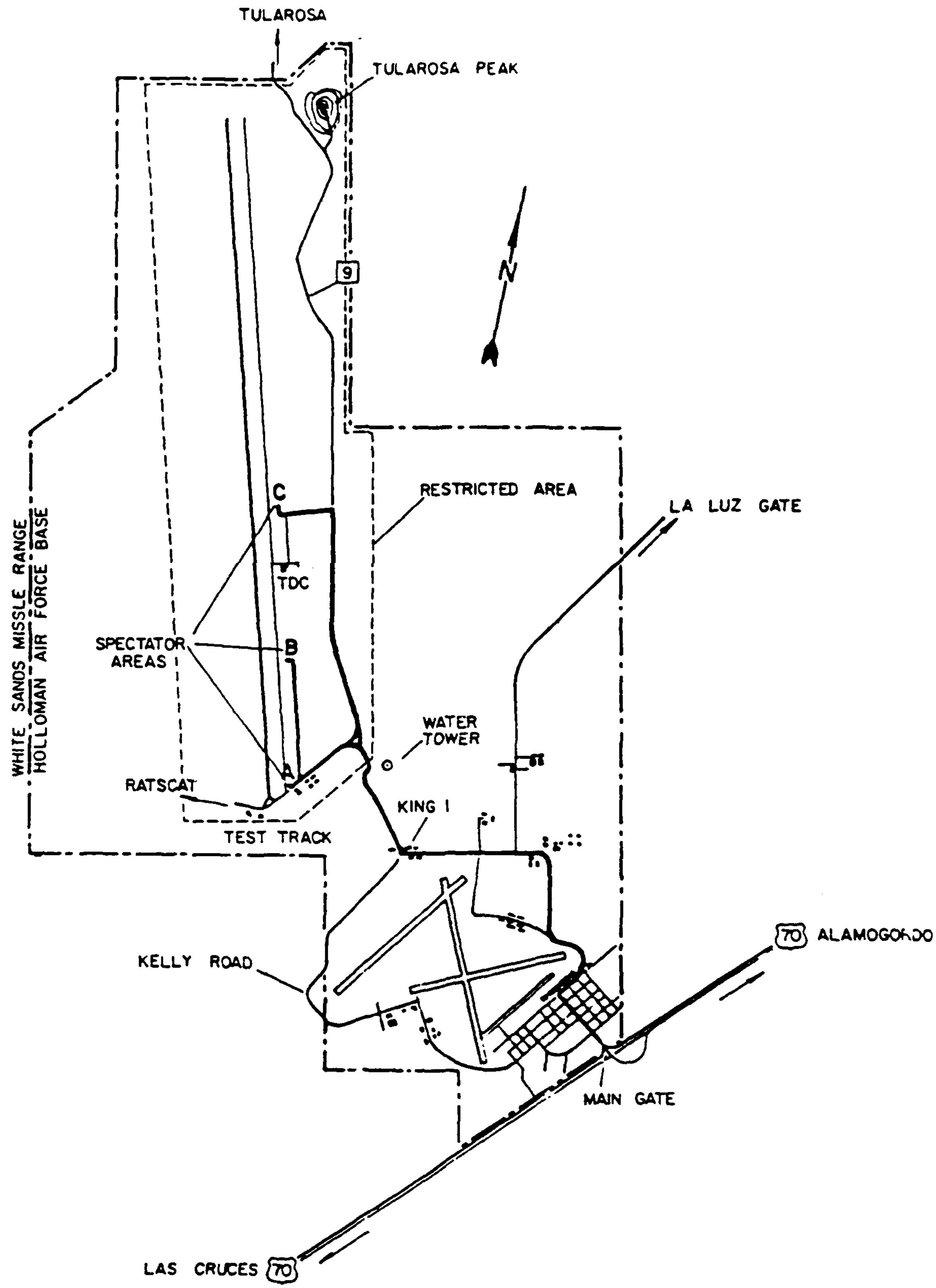
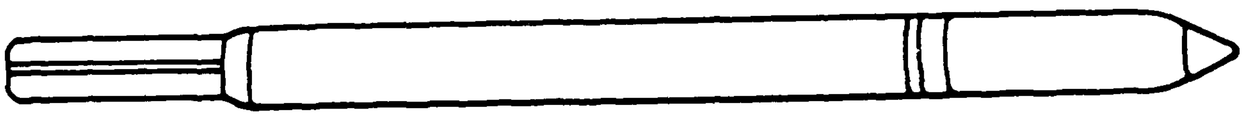


Figure 2

EVALUATION OF
ROCKET MOTOR EXHAUST COMBUSTION BY-PRODUCTS
HOLLOMAN AFB TEST TRACK NM
ZUNI ROCKET MOTOR



SOURCE: BUREAU OF NAVAL WEAPONS

APPLICATION: AIRCRAFT ROCKET

PROPELLANT: STANDARD X-8

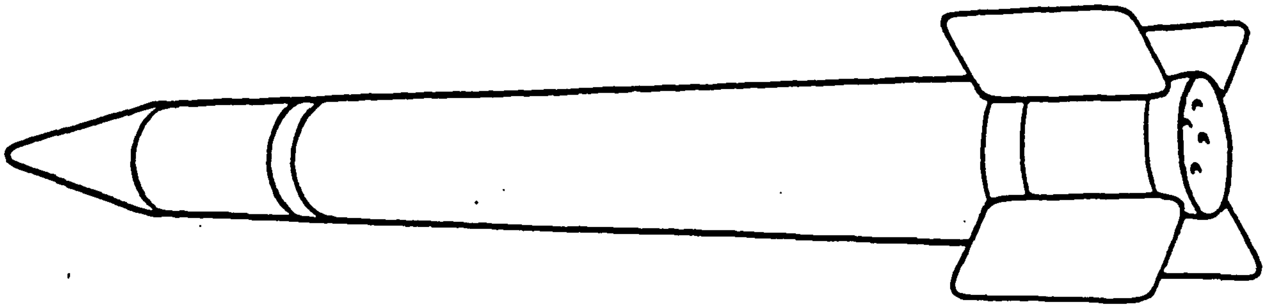
FLAME TEMPERATURE: 3784 °F

CASE: LENGTH (WITHOUT NOZZLES)................................ 61.698 IN.
O. D. .... 5.0 IN.
THICKNESS (NORMINAL).. 0.135 IN.

LINER:... ETHYLCELLULOSE

Figure 3

EVALUATION OF
ROCKET MOTOR EXHAUST COMBUSTION BY-PRODUCTS
HOLLOMAN AFB TEST TRACK NM
HIGH VELOCITY AIRCRAFT ROCKET (HVAR)



SOURCE: BUREAU OF NAVAL WEAPONS

APPLICATION: PROPULSION ROCKET

PROPELLANT: NITROCELLULOSE-NITROGLYCERIN

FLAME TEMPERATURE: 3960 °F

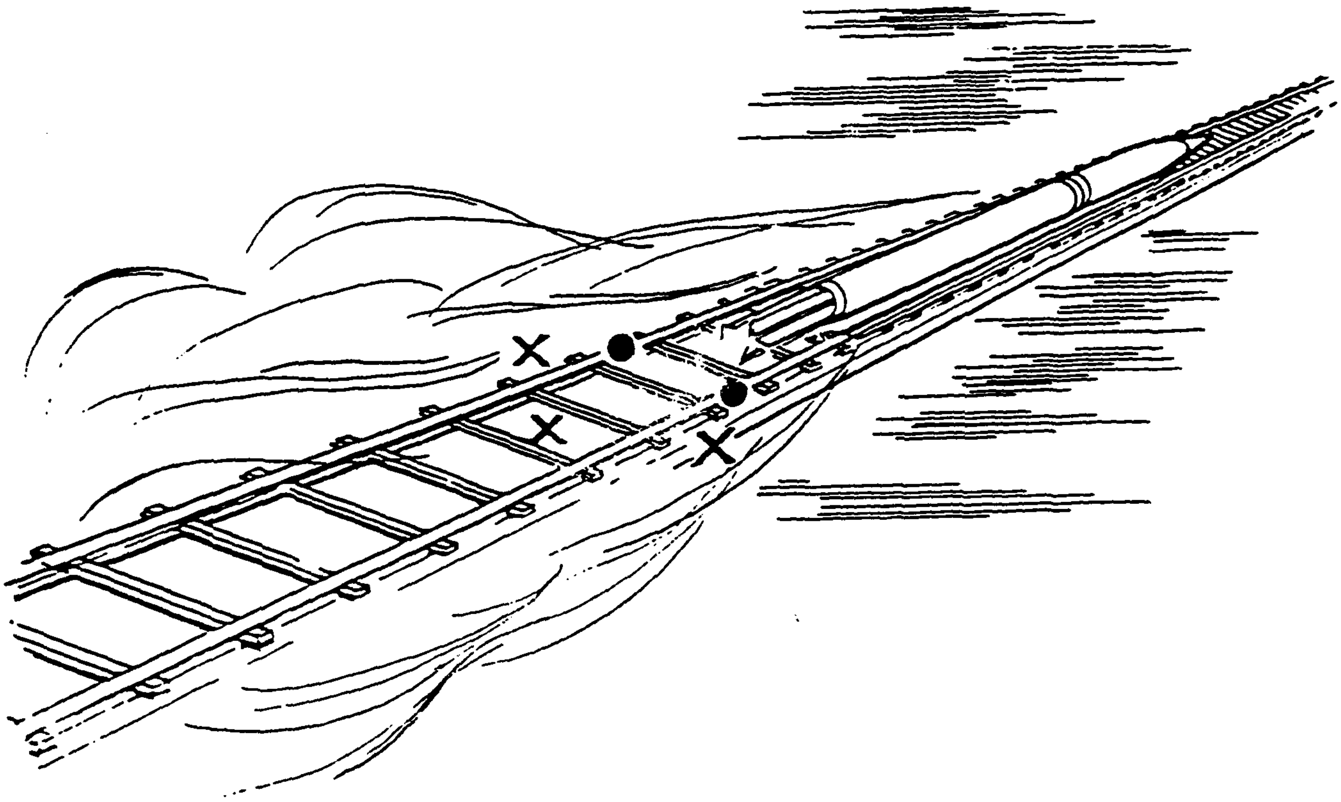
CASE:	LENGTH (WITHOUT NOZZLES)	51.31 IN.
	O.D. (WITH INSULATION)	5.0 IN
	THICKNESS (NOMINAL)	0.19 IN.

LINER: COMPOSITION.................CELLULOSE ACETATE

Figure 4

EVALUATION OF
ROCKET MOTOR EXHAUST COMBUSTION BY-PRODUCTS
HOLLOMAN AFB TEST TRACK NM
ZUNI ROCKET MOTOR SAMPLING LOCATIONS

(26 Aug 88)



METEROLOGICAL DATA

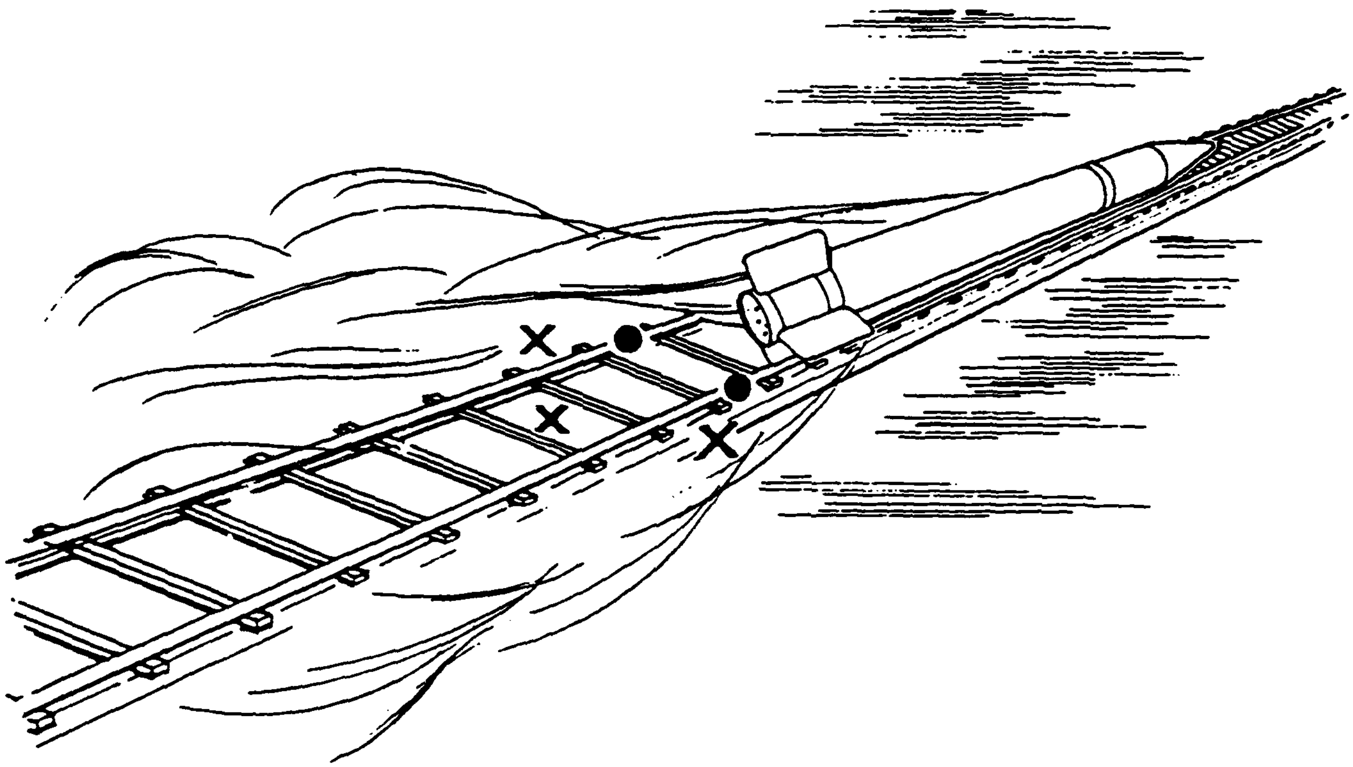
Temp: 95 ^{o}F
Barometric Pressure: 29.8 in.
Relative Humidity: 32%
Wind Speed: 3 Knots

X = TUBE SAMPLES

● = BAG SAMPLES

Figure 5

EVALUATION OF
ROCKET MOTOR EXHAUST COMBUSTION BY-PRODUCTS
HOLLOMAN AFB TEST TRACK NM
(HVAR) ROCKET MOTOR SAMPLING LOCATIONS
(31 Aug 88)



METEROLOGICAL DATA

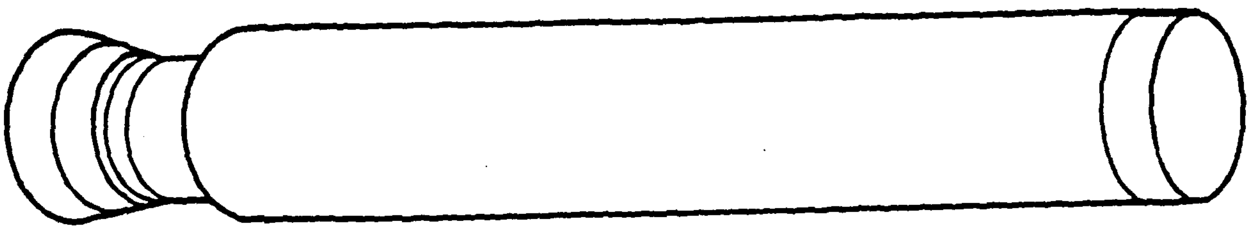
Temp: 97 ^{o}F
Barometric Pressure: 29.7 in.
Relative Humidity: 36%
Wind Speed: 3 Knots

X = TUBE SAMPLES

● = BAG SAMPLES

Figure 6

EVALUATION OF
ROCKET MOTOR EXHAUST COMBUSTION BY-PRODUCTS
HOLLOMAN AFB TEST TRACK NM
NIKE HERCULES BOOSTER



SOURCE: ARMY MISSILE COMMAND

APPLICATION: THIS MOTER HAS BEEN SUCCESFULLY EMPLOYED IN VARIOUS NASA SPONSORED SPACE PROBE FIRINGS.

PROPELLANT: NITROCELLUCOSE, NITROGLYCERIN, TRIACETIN

FLAME: TEMPERATURE: 4290 °F

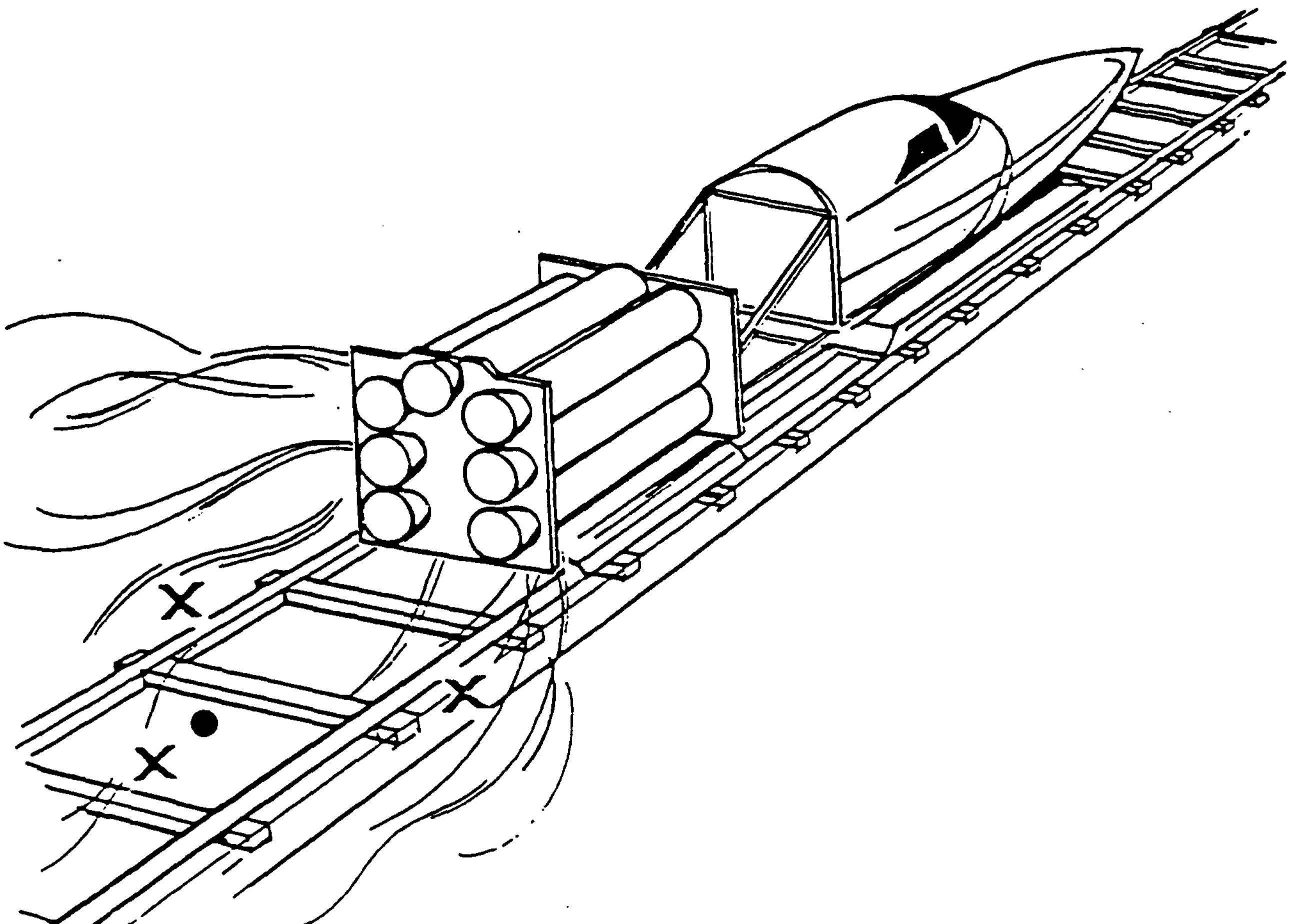
CASE: LENGTH (WITHOUT NOZZLE)................................ 105.5 IN.
O. D. .... 17.57 IN.
THICKNESS.. 0.114 IN.

LINER: COMPOSITION.. FLAMERMASTIC

Figure 7

EVALUATION OF
ROCKET MOTOR EXHAUST COMBUSTION BY-PRODUCTS
HOLLOMAN AFB TEST TRACK NM
NIKE ROCKET MOTOR SAMPLING LOCATIONS

(16 Nov 88)



METEROLOGICAL DATA

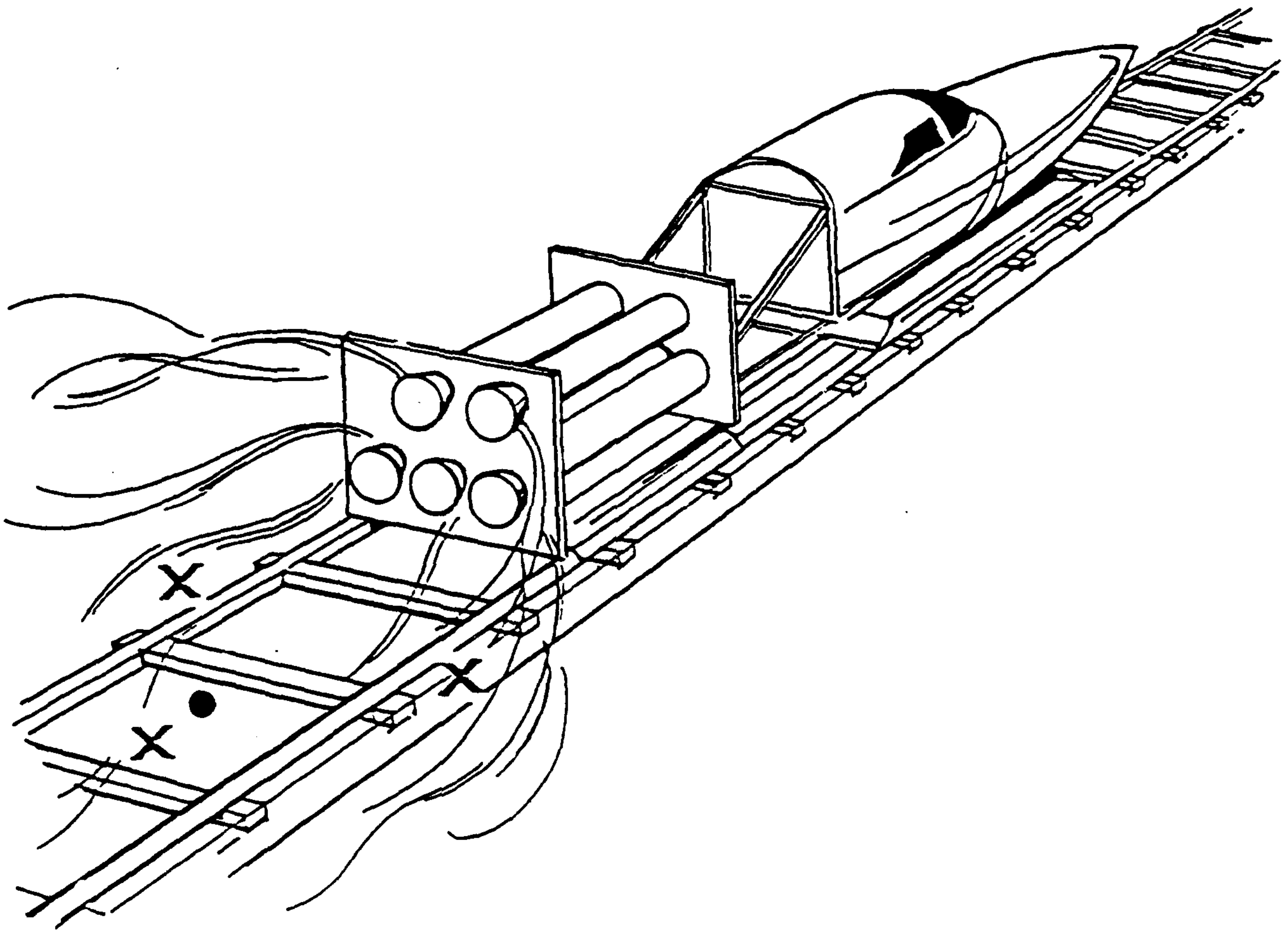
Temp: 72 ^{o}F
Barometric Pressure: 29.9 in.
Relative Humidity: 36%
Wind Speed: 1 Knot

Figure 8

EVALUATION OF ROCKET MOTOR EXHAUST COMBUSTION BY-PRODUCTS HOLLOMAN AFB TEST TRACK NM

NIKE ROCKET MOTOR SAMPLING LOCATIONS

(17 Nov 88)



X = TUBE SAMPLES

● = BAG SAMPLES

METEROLOGICAL DATA

Temp: 69 °F
Barometric Pressure: 30.0 in.
Relative Humidity: 32%
Wind Speed: 2 Knots

Figure 9

CSI 2200 NO/NO_2 Analyzer

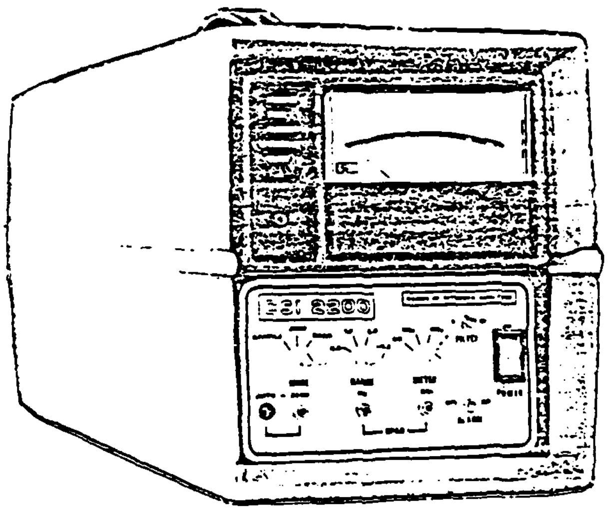


Figure 10

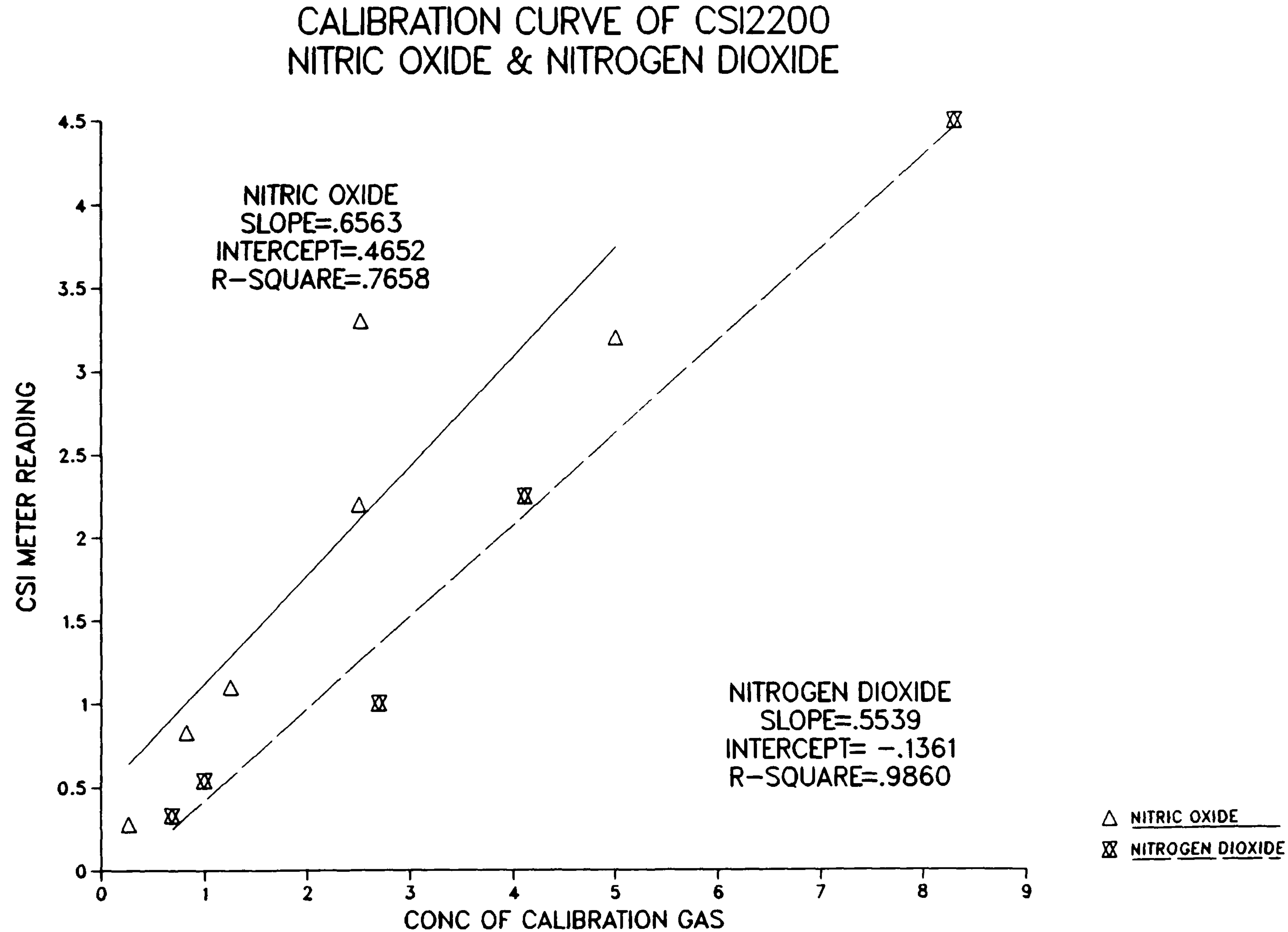

CALIBRATION CURVE OF CSI2200
NITRIC OXIDE & NITROGEN DIOXIDE
NITRIC OXIDE
SLOPE=.6563
INTERCEPT=.4652
R-SQUARE=.7658
NITROGEN DIOXIDE
SLOPE=.5539
INTERCEPT= -.1361
R-SQUARE=.9860
CSI METER READING
CONC OF CALIBRATION GAS
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
1
2
3
4
5
6
7
8
9
NITRIC OXIDE
NITROGEN DIOXIDE

Figure 11

CO 101 ANALYZER

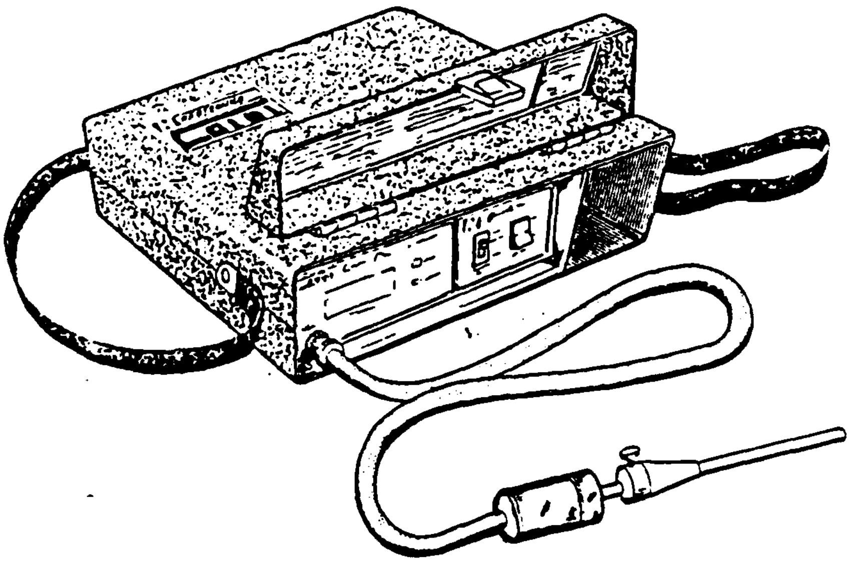


Figure 12

INTERSCAN HCl ANALYZER

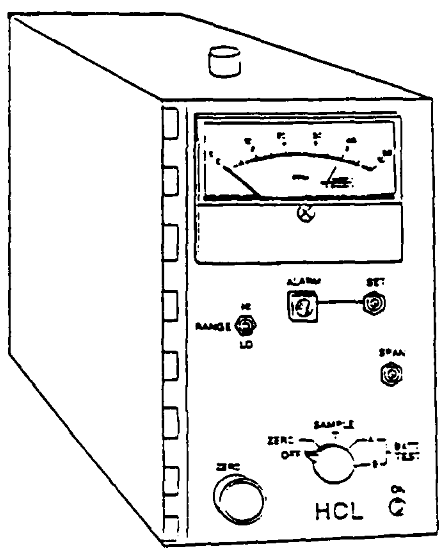


TABLE 1. Rocket Motor Exhaust Chemical Ingredients*

COMPONENT NAME	
Carbon Monoxide	(CO)
Carbon Dioxide	(CO_2)
Nitrogen	(N_2)
Nitric Oxide	(NO)
Nitrogen Dioxide	(NO_2)
Hydrogen Sulfide	(H_2S)
Hydrogen	(H_2)
Hydrogen Chloride	(HCl)
Sulfur	(S)
Chloride	($Cl2$)
Water	(H_2O)

* Data from U.S. Naval Ordnance Test Station and OSRD Report 2544, California Institute of Technology, unclassified, (1946)

TABLE 2. Frequently Used Rocket Motors

NAME	FUEL	LINER
Nike, M5E1	Nitrocellulose/ Nitroglycerin/ Triacetin	Flamermastic*
Nike Sustainer	Ammonium perchlorate/ polysulfide	Polysulfide Rubber
15 KS 1000	Insufficient Data	
Sergeant	Ammonium perchlorate/ polysulfide	Polysulfide rubber
Genie	Ammonium perchlorate/	Polyhydrocarbons polybutadiene (rubber)
HVAR	JPN - Nitrocellulose/ Nitroglycerin	Cellulose acetate
Zuni	Standard X-8	Ethyl Cellulose
M58A2	Ammonium perchlorate/ Polysulfide	Polysulfide Rubber
Honest John	Nitrocellulose/ Nitroglycerin Triacetin	Cellulose Acetate
Little John	Nitrocellulose/ Nitroglycerin/ 2 Nitrodiphenylamine	Pyrolock*

* Sufficient information was not available to determine the chemical constituents of this product.

TABLE 3. Sampling Protocol

CHEMICAL NAME	COLLECTION METHOD	FLOW RATE (L/MIN)	TIME (MIN)	VOLUME (LITERS)
Camphor	CHARCOAL TUBE	1	20	20
Camphor	TENAX TUBE	1	20	20
Diethyl phthalate	CHARCOAL TUBE	1	20	20
Diethyl phthalate	CHARCOAL TUBE	1	20	20
Hydrogen sulfide	IMPINGER (Cadmium hydroxide)	0.2	45	9

DIRECT READING INSTRUMENTS

INSTRUMENT NAME	CHEMICAL NAME	SAMPLE TYPE	DETECTOR USED
CSI 2200	NITRIC OXIDE	BAG SAMPLE	Chemiluminescent light
CSI 2200	NITROGEN DIOXIDE	BAG SAMPLE	Chemiluminescent light
CO 101	CARBON MONOXIDE	BAG SAMPLE	Electrochemical diffusion
INTERSCAN	HYDROGEN CHLORIDE	AREA READING	Electrochemical voltametric

TABLE 4. Zuni Rocket Motor Direct Reading Instruments Results

CHEMICAL NAME		STANDARD	
Carbon Monoxide	(CO)	400 ppm	(STEL)
Hydrogen Chloride	(HCl)	5 ppm	(Ceiling)
Nitrogen Dioxide	(NO_2)	5 ppm	(Ceiling)
Nitric Oxide	(NO)	125 ppm	(Excursion Limit, 5 times 25 ppm [TWA])

INSTRUMENT USED	SAMPLE TYPE	CHEMICAL NAME	CONC (PPM)
CSI 2200	Bag Sample 1	NO	1.0
CSI 2200	Bag Sample 2*	NO	<0.5
CSI 2200	Bag Sample 1	NO_2	2.0
CSI 2200	Bag Sample 2	NO_2	<0.5
CO 101	Bag Sample 1	CO	23.0
CO 101	Bag Sample 2	CO	6.0
INTERSCAN	Area Reading@	HCl	3.8
INTERSCAN	Area Reading	HCl	3.5
INTERSCAN	Area Reading	HCl	2.0
INTERSCAN	Area Reading	HCl	1.0
INTERSCAN	Area Reading@@	HCl	0.2

* Prevailing winds are suspected of directing rocket motor exhaust away from bag.

@ Area Reading taken 10 minutes after launch. Readings were taken in a 1 foot radius around the sled.

@@ Area Reading 25 minutes after launch.

TABLE 5. HVAR Rocket Motor Direct Reading Instruments Results

CHEMICAL NAME		STANDARD
Carbon Monoxide	(CO)	400 ppm (STEL)
Hydrogen Chloride	(HCl)	5 ppm (Ceiling)
Nitrogen Dioxide	(NO_2)	5 ppm (Ceiling)
Nitric Oxide	(NO)	125 ppm (Excursion Limit, 5 times 25 ppm [TWA])

INSTRUMENT USED	SAMPLE TYPE	CHEMICAL NAME	CONC (PPM)
CSI 2200	Bag Sample 1	NO	0.2
CSI 2200	Bag Sample 2*	NO	<0.5
CSI 2200	Bag Sample 1	NO_2	0.3
CSI 2200	Bag Sample 2	NO_2	<0.5
CO 101	Bag Sample 1	CO	1.0
CO 101	Bag Sample 2	CO	no reading
INTERSCAN	Area Reading@	HCl	<1.0

* Prevailing winds are suspected of directing rocket motor exhaust away from bag.

@ Area reading 10 minutes after launch.

TABLE 6. Hydrogen Sulfide Air Sample Results

CHEMICAL NAME		STANDARD	LIMIT OF DETECTION
Hydrogen Sulfide	(H_2S)	21 mg/m^3 (STEL)	0.1 mg/m^3

SAMPLE NO.	ROCKET MOTOR TYPE	CHEMICAL NAME	CONC (mg/m^3)
SX889007	Zuni	H_2S	<0.1
SX889008	Zuni	H_2S	<0.1
SX889009	Zuni	H_2S	<0.1
SX889010	Zuni	H_2S	<0.1
SX889011	Zuni	H_2S	<0.1
SX889025	HVAR	H_2S	<0.1
SX889026	HVAR	H_2S	<0.1
SX889027	HVAR	H_2S	<0.1
SX889028	BLANK	H_2S	<0.1

TABLE 7. GC/MS Tenax and Charcoal Tube Qualitative Results*

SAMPLE NO.	ROCKET MOTOR TYPE	COLLECTION MEDIA	GC/MS RESULTS
SX885526	ZUNI	CHARCOAL TUBE	UNKNOWN**
SX885530	ZUNI	TENAX TUBE	Naphthalene 2-Pentanone Akyl benzene Methyl Benzene Diethyl phthalate@
SX885546	HVAR	CHARCOAL TUBE	Camphor@ Diethyl phthalate@
SX885540	HVAR	TENAX TUBE	Diethyl phthalate

* Samples were extracted with carbon disulfide, then aliquots were analyzed by capillary gas chromatography/mass spectrometry (GC/MS).
** Could not identify, major ion 173 amu (atomic mass units).
@ Major peak (s) (approximately 90% of total).
Limit of detection, approximately 0.0003 mg/m^3.

TABLE 8. Nike Rocket Motor Direct Reading Instruments Results (16 Nov 88)

CHEMICAL NAME		STANDARD
Carbon Monoxide	(CO)	400 ppm (STEL)
Hydrogen Chloride	(HCl)	5 ppm (Ceiling)
Nitrogen Dioxide	(NO_2)	5 ppm (Ceiling)
Nitric Oxide	(NO)	125 ppm (Excursion Limit, 5 times 25 ppm [TWA])

INSTRUMENT USED	SAMPLE TYPE	CHEMICAL NAME	CONC. (PPM)
CSI 2200	Bag Sample	NO	>5.0*
CSI 2200	Bag Sample	NO_2	>5.0*
CO 101	Bag Sample	CO	1000
INTERSCAN	Area Reading@	HCl	0.8
INTERSCAN	Area Reading	HCl	0.6
INTERSCAN	Area Reading	HCl	0.5
INTERSCAN	Area Reading@@	HCl	0.2

* Maximum reading of instrument.
@ Area Reading 10 minutes after launch. Readings were taken in a 1 foot radius around the test sled.
@@ Area Reading 25 minutes after launch.

TABLE 9. Nike Rocket Motor Direct Reading Instruments Results (17 Nov 88)

CHEMICAL NAME		STANDARD
Carbon Monoxide	(CO)	400 ppm (STEL)
Hydrogen Chloride	(HCl)	5 ppm (Ceiling)
Nitrogen Dioxide	(NO_2)	5 ppm (Ceiling)
Nitric Oxide	(NO)	125 ppm (Excursion Limit, 5 times 25 ppm [TWA])

INSTRUMENT USED	SAMPLE TYPE	CHEMICAL NAME	CONC (PPM)
CSI 2200	Bag Sample	NO	>5.0*
CSI 2200	Bag Sample	NO_2	>5.0*
CO 101	Bag Sample	CO	255.0
INTERSCAN	Area Reading@	HCl	0.8
INTERSCAN	Area Reading	HCl	0.6
INTERSCAN	Area Reading	HCl	0.5
INTERSCAN	Area Reading@@	HCl	0.1

* Maximum reading of instrument.
@ Reading taken 10 minutes after launch. Readings were taken in a 1 foot radius around the test sled.
@@ Reading taken 25 minutes after launch.

TABLE 10. Hydrogen Sulfide Air Sample Results

CHEMICAL NAME	STANDARD	LIMIT OF DETECTION
Hydrogen Sulfide (H_2S)	21 mg/m^3 (STEL)	0.1 mg/m^3

SAMPLE NO.	ROCKET TYPE	CHEMICAL NAME	CONC (mg/m^3)
SX889062	Nike	H_2S	<0.1
SX889063	Nike	H_2S	<0.1
SX889064	Nike	H_2S	<0.1
SX889065	Nike	H_2S	<0.1
SX889066	Nike	H_2S	<0.1
SX889067	Nike	H_2S	<0.1
SX889068	Blank	H_2S	<0.1

TABLE 11. GC/MS Charcoal Tube Qualitative Results*

SAMPLE NO.	COLLECTION MEDIA	GC/MS RESULTS
SX889060	CHARCOAL TUBE	Three peaks were detected. Major peak was identified as diethyl phthalate (approximately 94% of total). The two other peaks could not be identified. They were approximately 3% of the total unknown peaks.
SX889061	CHARCOAL TUBE	Two peaks were detected. Major peak was identified as diethyl phthalate (approximately 98-99% of total). Second peak was tentatively identified as thiophene.

* Samples were extracted with carbon disulfide, then aliquots were analyzed by capillary gas chromatography/mass spectrometry (GC/MS).
Limit of Detection, approximately 0.0003 mg/m³.

TABLE 12. Diethyl Phthalate Air Sampling Results

CHEMICAL NAME	STANDARD
Diethyl phthalate (DEP)	25 mg/m³ (Excursion Limit, 5 times 5 mg/m³ [TWA])

SAMPLE NO.	ROCKET MOTOR TYPE	SAMPLE MEDIA	CHEMICAL NAME	CONC (mg/m³)
SX889040	Nike	Charcoal	DEP	15.0
SX889041	Nike	Charcoal	DEP	76.0*
SX889042	Nike	Charcoal	DEP	28.0*
SX889043	Nike	Charcoal	DEP	39.0*
SX889044	Nike	Charcoal	DEP	12.0
SX889045	Nike	Charcoal	DEP	8.0
SX889046	Nike	Charcoal	BLANK	<0.1
SX889047	Nike	Charcoal	DEP	7.0
SX889048	Nike	Charcoal	DEP	22.0
SX889049	Nike	Charcoal	DEP	11.0

* Exceeded 25 mg/m³, the Excursion Limit.
Limit of Detection, 0.1 mg/m³.

DISTRIBUTION

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Defense Technical Information Center (DTIC) Cameron Station Alexandria VA 22304-6145	2
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HQ 6585th Test Group/TKOS (Mr Haden) Holloman AFB NM 88330-5300	3
HQ HSD/XAE Brooks AFB TX 78235-5000	1